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THE PERFORMANCE CHARACTERISTICS OF GEOMETRICALLY SIMILAR BISTABLE AMPLIFIERS

FINAL REPORT

by

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ABSTRACT

The results of a comprehensive study of the comparative performance characteristics of geometrically similar vented and unvented bistable amplifiers, together with their actual dimensions, are presented. The Reynolds number in the tests ranged from 9,750 to 60,000, Mach number from 0.07 to 0.42, and the power jet velocity from 75 to 460 ft/sec. Each amplifier as conceived and designed was capable of giving a maximum of geometric flexibility which enabled a systematic evaluation of the shape and location of the splitter plate and Coanda-walls. It was found, within the range of Reynolds and Mach numbers tested, that certain gain characteristics and the range of operation of a given unvented amplifier overlap, within a narrow range of P_o/P_s and Q_o/Q_s values, with the corresponding gain characteristics and the range of operation of the vented amplifier. It was also found that a convex-walled amplifier with proper geometry exhibits considerably better performance characteristics than are normally associated with such devices. Finally, a new bistable amplifier with vents located in the load ports has been introduced.

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HARRY DIAMOND LABORATORIES OF THE
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1. INTRODUCTION

1.1 GENERAL COMMENTS ON BISTABLE AMPLIFIERS

Bistable fluid amplifiers are devices that can perform as logic and computing elements in miniaturized fluid circuitry. The research in the past decade has shown that there are numerous parameters which affect the static and dynamic performance characteristics of a bistable amplifier. Among those most critical are the wall offset, control nozzle width, output size, diffuser angle, wall angle, wall shape, splitter shape, width and location, vent size and location, wall length, aspect ratio, output flow, and the Reynolds and Mach numbers.

Wall offset affects the pressure recovery, the amount of control flow necessary to switch the amplifier, the attachment distance, and the stability of the amplifier, particularly under fully blocked output-port conditions.

Control nozzle width changes the pressure recovery considerably, particularly for control nozzle widths between 0.5 and 1.5 power nozzle widths.

The variation of the final exit width, which also changes the diffuser area ratio, has, in general, little effect in the range of 7 to 10 nozzle widths.

The diffuser angle causes a small variation in pressure recovery for diffuser angles between 5 and 10 degrees. The optimum value is approximately 7 or 8 degrees.

The wall angle has considerable effect on the pressure recovery. In fact, the recovery can drop by as much as 30 percent of the maximum when the wall angle is increased from 10 to 15 degrees. Equally important is the wall shape. Various geometries such as straight, concave, and convex have been used. It now appears that a convex-walled amplifier offers considerably better performance characteristics than are normally associated with such devices.

Splitter shape, width, and location play major roles on the performance of the amplifier. The position of the splitter, relative to the vents in a vented amplifier, is important for relatively low output flows. For large output flows, the pressure recovery is relatively independent of the splitter location. The variation of the splitter width from zero to 2 nozzle widths has a small effect on the pressure recovery at low output flows and an apparent optimum value is approximately 1.5 nozzle widths. When the splitter width is changed, other geometry is also changed and it is not possible to determine the effects of the splitter width independently. The splitter shape, such as sharp-edged, straight-faced, or cusped, has profound effects on the pressure recovery, vent flow, and the switching time. Among the various splitter shapes studies in the literature, the one with a circular cusp offers the best pressure recovery and amplifier stability [1, 2, 3]*.

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* Numbers in brackets designate references listed in the Bibliography

The vent size appears to be important only for low flow rates. As the vent size is reduced, the maximum pressure recovery increases. However, it is important to note that the highest pressure recovery (obtained with a fully blocked load port condition) requires a sufficiently large vent to prevent premature switching. This indicates the existence of an optimum vent size. It appears that this optimum is about 3 nozzle widths.

For low output flows, an increase in the wall length from 7 to 11 power nozzle widths can lower the pressure recovery by about 20 percent. At large output flow rates, the wall length is relatively unimportant.

The past and present experiments have shown that the pressure recovery is nearly independent of the aspect ratio in the range of 2 to 4. The signal-to-noise ratio is, however, significantly affected by the aspect ratio. For very small aspect ratios (0.5 to 1), the length of the potential core of the power jet and hence, the noise free region of the jet considerably increases with decreasing aspect ratio. An engineering compromise between the signal-to-noise ratio and the pressure recovery indicates an aspect ratio of about 1.5.

Evidently, the pressure recovery increases with decreasing output flow. Operation with blocked load port is possible only with vented amplifiers. It should be noted in passing that the question of the location of vents, as to whether they should be located in the vicinity of the splitter plate or within the load port, will be discussed later.

The effects of Reynolds and Mach numbers are indeed exceedingly complex not only on the flow in the interaction region but also on the development of flow in the nozzle. The development of the laminar or turbulent boundary layers in the nozzles and its subsequent effect on the jet reattachment depend not only on the Reynolds number based on the width or the hydraulic radius of the nozzle but also on the Reynolds number based on the length of the nozzle. For very short nozzles, the boundary layers are underdeveloped and hence negligible relative to the nozzle width. For very long nozzles, the flow is fully developed by the time it reaches the nozzle exit. For such a jet, the virtual origin of the jet is significantly altered and the characteristics of the jet reattachment, jet curvature, and the entrainment interface are changed. Evidently, the effect of the Reynolds number is small provided that the boundary layers are thin as compared with the nozzle width.

In order to arrive at the optimum values of the parameters cited above, it is necessary to either build a very large number of amplifiers, each of which has a fixed-geometry, or to build a single amplifier with a maximum of geometric flexibility in which the value of the various parameters can be systematically varied. Obviously, the construction of a large number of models would be quite expensive and extremely time-consuming. Almost as difficult are the problems involved in the construction of an amplifier with flexible geometry, not the least of which are the leakage problem and the problem of providing suitable inlets and outlets for the control jets and load ports. Nevertheless, the use of a variable-geometry amplifier is the best and perhaps the only systematic means of studying the characteristics of an amplifier.

The development of a variable-geometry amplifier is, in turn, based on water table studies where the various components of the amplifier could be moved or changed easily. The simplicity afforded by the water table or the hydraulic analogy, however, is somewhat offset by the qualitative nature of the results. Despite that, considerable time and effort are saved by the analogy in the preliminary design of various types of amplifiers.

Several sets of amplifiers were developed in the present investigation through the use of a 2 ft. wide and 6 ft. long water table. The details of the experimental equipment and procedure and the measurements made were described in references [4, 5, and 6]. Upon the completion of the mostly qualitative and partly quantitative water table studies, three sets of two-dimensional variable-geometry bistable amplifiers were built and each set was tested with or without the vents for different arrangements of various components and for different velocities, with air as the working fluid.

1.2 OBJECTIVES

The overall objective of this research program was to develop, through analysis and experimentation, stable and high-performance bistable amplifiers with or without vents and to establish relationships between the gain characteristics of a vented and unvented, geometrically similar, bistable amplifier. It is found that due to a lack of any general analytical work on designing a unit with optimum static and dynamic performance characteristics, the technique developed in this work is the only possible method of optimizing such a bistable unit.

2. EXPERIMENTAL EQUIPMENT AND TEST PROCEDURE

The schematic diagram of the test set-up used for most of the experiments with air is shown in Fig. 1.

Once the particular supply flow as set by means of the valve in the power jet line, the load restrictor valves in both load ports were fully opened and the pressures and flow rates recorded. Then the load restrictor valve in the active side load port was partially closed to permit less flow through that port and the pressures were again recorded. This procedure was continued with step by step closure of the restrictor valve until the flow out of the active port was completely stopped or when the jet switched under the active port loading. Subsequently, the supply flow rate was changed and the experiments were repeated as outlined above with both open and closed control ports.

The amount of control flow required for switching was determined as follows: A desired flow rate was set for the power jet, and both load ports were left fully open. The valve for the control port on the active side was then opened until there was sufficient flow in the port to switch the power jet to the opposite wall of the interaction region. This quantity of flow was then recorded. Subsequently, data points were taken with the active port load restriction valve at settings ranging from wide-open to fully shut-off in order to simulate the complete range of expected load effects ranging from simple piston loads to loads presented by the control ports of other logic elements. Experiments were then repeated with different power jet velocities and interchanging the roles played by the active and passive load ports for both the vented and unvented amplifiers. It is important to note that when the flow in a vented amplifier was directed toward the active port (port-A), the passive port (port-B) remained at ambient pressure or slightly lower due to suction, and opening or closing the passive port had no effect on the flow and pressure in the active port, indicating an effective decoupling between the two load ports. Decoupling was equally effective when the flow as directed toward the port-B due to symmetry of the design. It was also observed that varying the restriction in the passive port had no effect on control pressures and that raising control flows to any level short of that needed for switching the jet had little or no effect on the output.

3. CHARACTERISTICS OF THE AMPLIFIERS WITH LONG NOZZLES AND VARIOUS DESIGN CONSIDERATIONS

Initially, three sets of variable-geometry amplifiers with relatively long nozzles were developed through the use of the hydraulic analogy and each set was tested for different arrangements of various components and for different velocities. Each unit had an aspect ratio of four with a throat width of w = 0.25 in. Figures 2, 3, and 4 show the general design of each set and the dimensions of the particular unit which exhibited the highest gain characteristics relative to all other units in a given set. Figure 5 shows the design details of the splitter plate, Coanda-walls, and vents. It is apparent that all three sets finally had, with the exception of the Coanda-walls, identical geometrical characteristics to yield highest performance characteristics relative to all other units in their class.

The first set (Fig. 2) is a straight-walled vented or unvented amplifier. Figures 3 and 4 show concave Coanda-walled and convex Coanda-walled vented or unvented amplifiers. These two sets of amplifiers were included in the tests partly to determine whether the conclusions reached regarding the comparative performance characteristics of vented and unvented straight-walled amplifiers were valid for other types of bistable amplifiers and partly to determine whether it was possible to achieve higher gains by suitably curving the Coanda-walls. As will be seen later, the tests have provided affirmative answer to both queries.

Most of the researchers in the field of fluidics have dealt with straight-walled amplifiers as far as the bistable amplifiers are concerned. Although several studies have been conducted (references [7 and 8]) on the separation of a fluid jet from a curved wall, the results were not incorporated into the development of bistable amplifiers. It was, therefore, natural to investigate the effect of curved Coanda-walls on the performance of a bistable amplifier and in particular to find out if the stability and pressure recovery of the amplifier could be significantly increased.

Rechten [9] modified the straight Coanda-walls with concave curves and argued that the fluid pressure on the outer wall will have its highest values due to an interaction of the primary and secondary flows. However, the results reported herein have shown conclusively that the effect of such secondary flows and concave walls on the stability and pressure recovery of a bistable amplifier is practically insignificant and, under certain circumstances, measurably adverse. This result is not unexpected for the following reasons. In the interaction region of the amplifier, the energy, and consequently pressure, is lost by turbulent mixing and by wall shear forces. Since the loss due to mixing is significantly greater than the loss due to wall friction, pressure recovery depends to a large extent on the size of the attachment bubble. Hence, smaller pressure recovery at a given downstream position is obtained for a turbulent jet if the jet is attached to the wall further downstream, as in the case of a concave-walled amplifier. If, on the other hand, the jet is attached to the wall as soon as possible after leaving the nozzle, as in the case of a convex-walled amplifier, then it is possible to reduce the energy loss, to make use of the favorable alterations of the velocity profile along the curved wall, and to significantly increase the pressure recovery. The unfortunate fact, however, is that the pressure recovery, flow gain, and the stability do not all work in the same direction. In general, the greater the pressure recovery, the lower the gain and the larger the gain, the lower the stability. Although the problem is complex and the number of parameters involved is rather large, the range of values that these parameters can take on is surprisingly small. It is because of this reason that the use of a variable-geometry amplifier enables one to systematically vary these parameters within the range of their variability in arriving at an amplifier with good pressure recovery and stability characteristics.

4. DISCUSSION OF THE RESULTS OBTAINED WITH THE FIRST SET OF AMPLIFIERS

4.1 COMPARATIVE PERFORMANCE CHARACTERISTICS OF VENTED AND UNVENTED AMPLIFIERS

Figure 6 is a composite graph which compares the pressure recoveries for the closed control port operation, of vented and unvented straight-walled amplifier shown in Fig. 2. A typical throat velocity of 300 ft/sec (Re = 39,000, M = 0.273) was chosen for the comparison. It is observed that the pressure recovery for the vented version of the unit decreases steadily from values above 0.7 at zero active port flow of 0.45. The pressure recovery for the unvented amplifier begins with values of approximately 0.7 at Q_o/Q_s = 0.35 and decreases steadily to values of about 0.1 for the maximum active port flow of about 1.05. In other words, the values for the unvented amplifier are, under comparable conditions, extensions of the vented version of the same amplifier. This <u>does not</u>, however, <u>mean</u> that the receiver pressure-flow characteristics of the unvented amplifier are identical with those of the vented amplifier for normalized receiver pressures less than approximately 0.70. As a matter of fact, it is only within a narrow range of P_o/P_s (0.67 to 0.70) and Q_o/Q_s (0.35 to 0.45) values that the characteristics and the range of operation of the two amplifiers overlap. It is apparent that the vented amplifier under consideration does not yield Q_o/Q_s values larger than approximately 0.45 due to loss of flow through the vents and the unvented amplifier does not operate for Q_o/Q_s values smaller than approximately

0.35 due to the switching of the amplifier under the resulting active port loads. Thus, to assume that an unvented amplifier can operate throughout the flow range of a vented amplifier or vice versa is entirely unfounded and leads to erroneous interpretations of the characteristics of the amplifiers. Experiments have shown that these conclusions are equally valid for open control port operation and for all other power jet velocities tested.

Fig. 7 shows the power recovery versus pressure recovery for the vented and unvented versions of the same straight-walled amplifier for the same throat velocity of 300 ft/sec. It is seen again that the power recovery extends, as might have been anticipated, from a narrow range of common pressure recovery factors to left and right for the unvented and vented operations, respectively. It is in this comparison that a serious shortcoming of the vented amplifier is recognized. <u>The unvented unit has, for the same throat velocity, higher power recoveries</u>. However, this power recovery advantage may be offset by the fact that the unvented amplifier is load sensitive whereas the vented amplifier is load insensitive. The significant fact is that the addition of vents in itself does not, with the exception of rendering the unit load insensitive, radically alter the nature of the performance of the amplifier, but rather shifts the range and values of significant performance parameters.

4.2 <u>CONCAVE-COANDA WALLED AMPLIFIER</u>

Fig. 8 shows the pressure recoveries for the closed control port operation, of the vented and unvented concave-walled amplifiers.

Once again it is apparent that the pressure recovery curve of the unvented concave-walled unit is an extension of its vented version. As pointed out earlier, however, the performance of even the best concave-walled unit is inferior to that of the straight-walled unit. Evidently, curving of the walls away from the interaction region, and hence increasing the size of the interaction region and the attachment bubble, does not improve the characteristics of a bistable amplifier. This conclusion has been reached not only on the basis of the data shown in Fig. 8 but through a series of experiments with other nozzle velocities ranging from 75 to 460 ft/sec. Additional data are not presented for this configuration since it does not deserve further consideration for practical applications.

4.3 CONVEX-COANDA WALLED AMPLIFIER

The pressure recovery factors for the third set shown in Figs. 9 through 11 for throat velocities of 75, 300, and 490 ft/sec for both the open and closed control port modes. Also shown in these figures is the ideal pressure recovery curve for the open control port operation.

The idealized pressure recovery is determined by assuming the subsonic power jet of an ideal gas (no boundary layer effects) decelerates isentropically along the curved walls, the pressure at the exit plane of the power jet to be atmospheric, the power jet flow rate Q_s, active port flow rate Q_o, and the flow lost through the vents $(Q_s - Q_o)$. Then the velocities (assumed to be uniformly distributed) in the nozzle and the active port become

$$V_s = \frac{Q_s}{wt} \text{ and } V_o = \frac{Q_o}{1.5\ wt} \tag{1}$$

where t is the thickness or depth and w is the width of the power jet nozzle. The width of the output ports is 1.5w as shown in Figs. 2, 3, and 4.

Making use of Bernoulli's equation and ignoring the energy correction factors, one has

$$P_s = \rho \frac{V_s^2}{2} = P_o + \rho \frac{V_o^2}{2} \tag{2}$$

where P_s is the supply pressure or the dynamic pressure of the power jet. Combining and rearranging equations (1) and (2), yields

$$P_o/P_s = 1 - (1/2.25)\ (Q_o/Q_s)^2 \tag{3}$$

which is the equation of the ideal recovery curve shown in Figs. 9 through 11. A similar calculation cannot be carried out for the closed port operation since the pressure at the exit plane of the power jet is unknown and cannot be determined without the detailed consideration of the characteristics of the separation bubble.

It is apparent from Figs. 9 through 11 that the convex-walled unit (with long nozzles and relatively large aspect ratios) presented herein has good performance characteristics. It is also apparent that, for a given vent and control port condition, the pressure-recovery versus flow-recovery relation is practically independent of the Reynolds and Mach numbers within the range of velocities tested (flow rate corresponding to V_s = 460 ft/sec was the capacity of the test system for a prolonged test run.)

Although the question of wall shape in bistable amplifiers has received little attention, related previous studies, [10, 11], on the deflection of plane jets by inclined flat plates and circular cylinders have pointed out, among other significant differences, the effectiveness of a circular convex-wall in sustaining the attachment of a two-dimensional confined jet for larger angles of deflection. The present study confirms not only the validity of these observations but also the possibility of combining the effective jet-attachment characteristics of convex-walls with bistable amplifiers for the purpose of obtaining relatively larger pressure recoveries than are normally associated with such devices. It should be noted in passing that the curved convex-wall may possibly be replaced by multiple flat plates. According to Von Glahn, [12], multiple flat plates cause larger angles of deflection than a single flat plate.

4.4 CONTROL SIGNALS

Figure 12 shows the control flows required to switch the power jet for both the vented and unvented versions of the convex-walled amplifier. Despite the scatter of the data, it is apparent that Q_c/Q_s is relatively unaffected by active port load pressure for throat velocities ranging from 75 to 460 ft/sec. The data for V_s = 300 ft/sec, which fell between the data points for V_s = 75 and 460 ft/sec, are not shown in Fig. 12 in order to simplify the perusal of the figure.

Figure 13 shows the variation of normalized control pressure with pressure recovery for V_s = 75 ft/sec and V_s = 460 ft/sec for both the vented and unvented versions of the amplifier. P_{ca}/P_s is the normalized pressure at the active-side control-port when both control ports are fully closed. P_{ca}/P_s is the normalized active-side control-port switching pressure. When sufficient amount of fluid injected into the active-side control-port, P_{ca}/P_s rises to P_{cs}/P_s and causes switching. Finally, P_{dp}/P_s is the normalized passive-side control-port pressure when both control ports are closed. In other words, P_{dp}/P_s and P_{ca}/P_s occur simultaneously at the corresponding control ports.

It is apparent from Fig. 13 that the control pressures are load sensitive and rise slowly with increasing load or decreasing active port flow. The memory of the vented-amplifier is not, however, affected either by the load or by the closure of both control ports. Even for the largest flow reported herein, the power jet remained attached to the same sidewall when both control ports were closed.

5. CHARACTERISTICS OF THE AMPLIFIERS WITH STREAMLINED SHORT NOZZLES AND DESIGN MODIFICATIONS

Following the completion of the tests discussed above and the realization of the facts that the nozzle shape and boundary layers, as well as the aspect ratio, have, as previously noted, profound effects on the performance of the amplifier, a new amplifier with the same interaction-region geometry but with an aspect ratio of 2 and short streamlined nozzles has been constructed. The details of the nozzle geometry used for both the power and control jets are shown in Fig. 14. In addition, the diffuser angle of the load ports has been changed from zero to 7 degrees. Figure 15 shows a photograph of the amplifier modified along the lines described above.

A series of tests has been carried out with this modified model primarily for the purpose of determining the pressure-recovery factor since the preliminary experiments have indicated that the control-flow characteristics of the amplifier did not significantly change to warrant additional experiments beyond and above that presented in Fig. 13.

The pressure-recovery versus normalized active-port flow for the convex-walled, modified amplifier for open and closed control-port operations and for a mean power-jet velocity of 300 ft/sec is shown in Fig. 16. It is apparent from a comparison of Figs. 10 and 16 that the pressure-recovery of the modified model is relatively lower primarily because of the following reasons. The supply pressure, calculated through the use of the static pressure at the nozzle throat and the mean velocity of the power jet, is now relatively larger than that for a long, straight nozzle due to the elimination or the considerable reduction of the boundary layers. Secondly, both the jet reattachment distance and the entrainment characteristics of the jet have been changed due to the alterations of the jet profile and the turbulence structure by eliminating the boundary layers. Finally, the aspect ratio has been reduced from 4 to 2 with the proven consequence that the length of the potential core has been decreased. The combined effect of the consequence of these changes on the reduction of the pressure recovery has not been materially offset by the increase of the diffuser angle of the load ports. One is, therefore, inclined to conclude that an operational bistable amplifier which must have short and streamlined nozzles and relatively low aspect ratios (primarily because of the signal-to-noise ratio considerations) cannot have (with the vents as located in Fig. 4) maximum pressure recoveries in excess of approximately 0.75. It is, however, significant to point out that the convex-walled bistable amplifier is still superior in its performance to a geometrically similar straight-walled amplifier. This fact has recently been substantiated by others [13] following the earlier suggestions made by Sarpkaya and Kirshner [1], and Sarpkaya [2]. In fact, Özgü and Stenning [13] concluded, as previously pointed out by this writer [2] that the use of a convex attachment wall permits the use of very low setbacks with pressure recoveries higher than those for the straight-walled amplifier without significantly altering the dynamic switching characteristics of the amplifier.

6. A BISTABLE AMPLIFIER WITH A NEW VENT CONFIGURATION

The vents in all the existing bistable amplifiers are located in the vicinity of the splitter point or cusp. The experiments and simple reasoning show that under near or fully blocked load-port conditions, the flow in the vicinity of the vents and splitter are drastically altered, the flow in the off-side of the amplifier increased, the pressure near the vent on the on-side reduced near the ambient pressure, and finally and perhaps more significantly, the flow captured by the active load port includes that portion of the wall jet which includes also the boundary layer flow. [11] In other words, the low energy regions of the wall jet are not completely prevented from entering the load ports. In order to partly alleviate this problem and partly to make use of the otherwise favorable performance characteristics of the unvented bistable amplifiers, a new bistable-amplifier design has been conceived. In this design (see Fig. 17), the vents are located at the end of and within the load ports. The preliminary experiments have shown that the amplifier is load insensitive, the flow in the vicinity of the splitter plate is not disturbed, and more significantly, the pressure recovery is relatively higher (about 0.85 for the fully blocked output load-port condition.) A comprehensive study of the static and dynamic characteristics of this new design is currently underway and will be reported separately in the future.

7. CONCLUSIONS

Data taken on cusped, vented and unvented, bistable amplifiers of similar geometry, with the exception of Coanda-walls, have shown that certain gain characteristics and the range of operation of a given unvented amplifier overlap, within the range of Reynolds and Mach numbers tested, with the corresponding characteristics and the range of operation of the vented amplifier and that a bistable amplifier with convex-Coanda walls yields higher pressure recoveries than one with either concave or straight Coanda walls.

Secondly, the magnitude of the pressure recovery depends, among other things, on the nozzle length and the aspect ratio of the amplifier. Experiments show that short, streamlined nozzles and lower aspect ratios tend to reduce the pressure recovery but increase the signal-to-noise ratio.

Finally, a new bistable-amplifier design has been conceived and preliminary tests have been carried out. It appears that the proposed design will have superior performance characteristics relative to those with vents located near the edge of the splitter plate.

8. ACKNOWLEDGEMENTS

This research was sponsored by the Harry Diamond Laboratories of the U. S. Army Materiel Command. Many friendly discussions with Mr. J. M. Kirshner through the years on fluidics in general and on bistable amplifiers in particular are sincerely appreciated. Finally, special thanks are due to the able mechanics of the machine shop of the Department of Mechanical Engineering of the Naval Postgraduate School.

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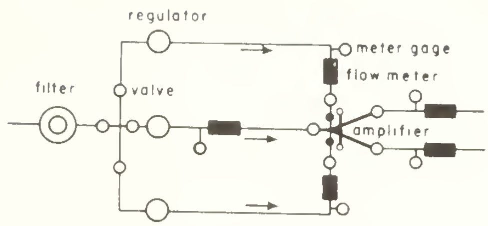

Fig. 1 Experimental test set-up

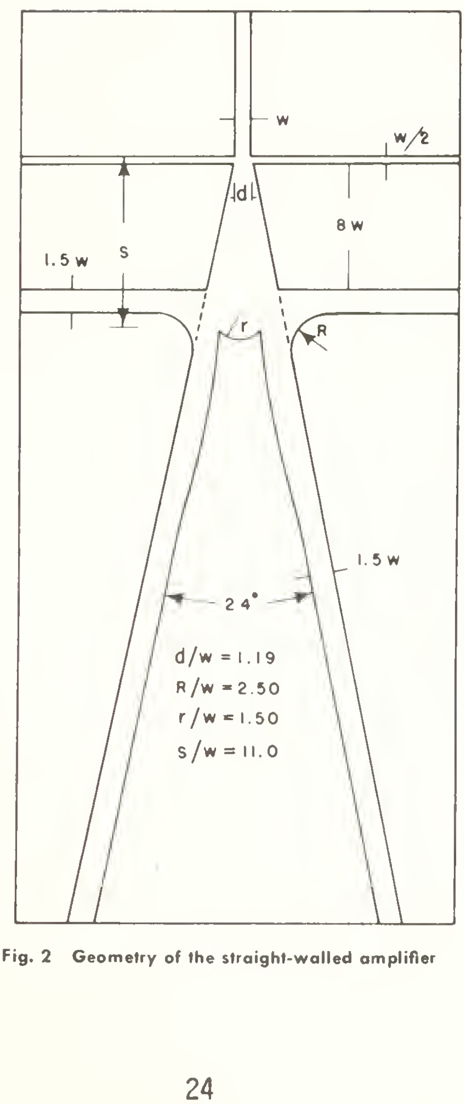

Fig. 2 Geometry of the straight-walled amplifier

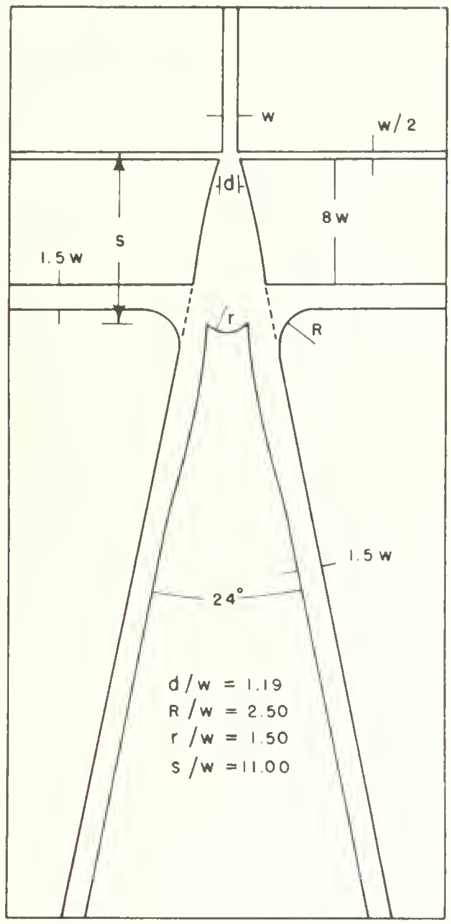

Fig. 3 Geometry of the concave-walled amplifier

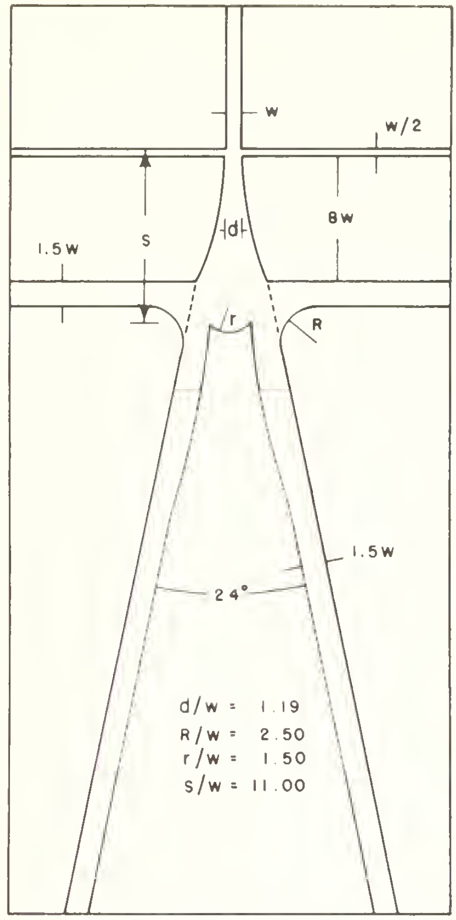

Fig. 4 Geometry of the convex-walled amplifier

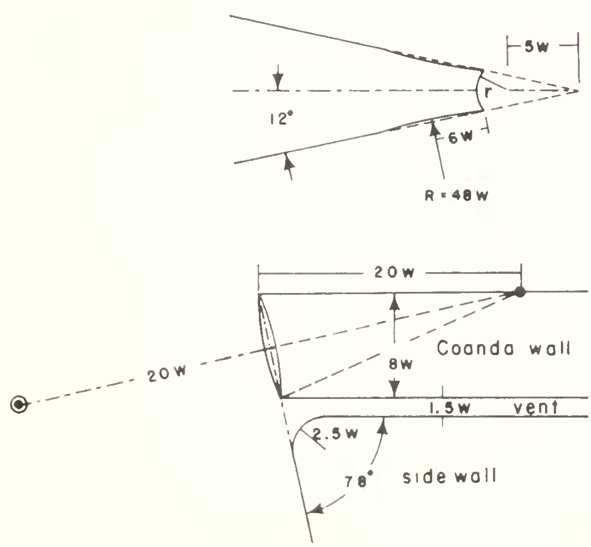

Fig. 5 Details of the splitter-plate, concave-wall, convex-wall, and vent geometry

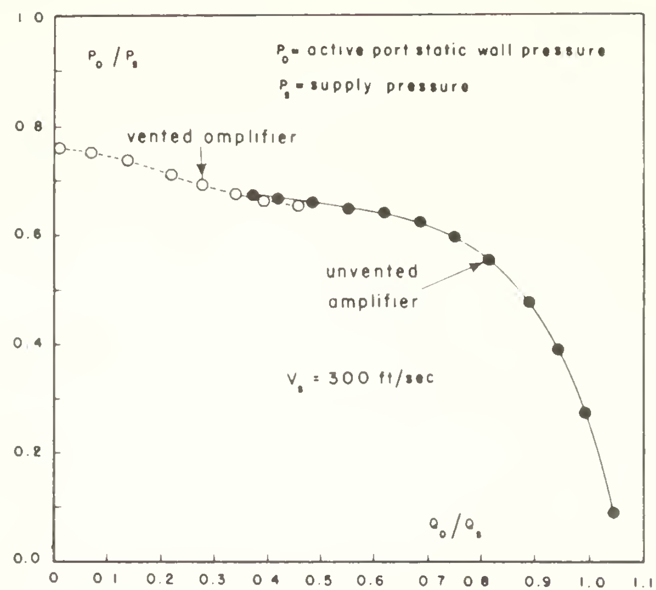

Fig. 6 Pressure-recovery versus normalized active-port flow for the straight-walled amplifier (closed control ports)

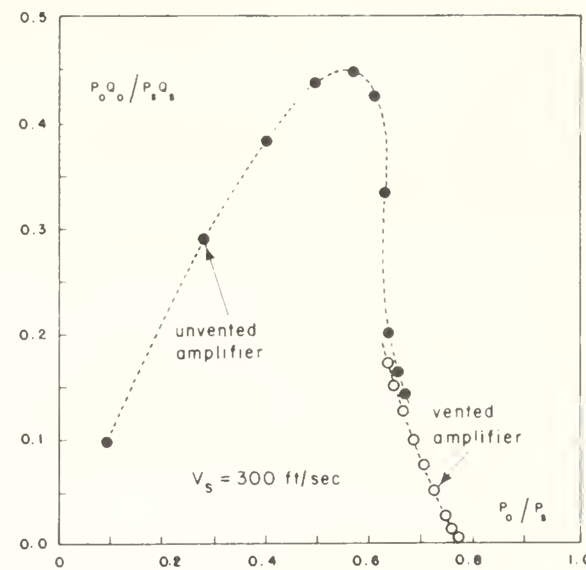

Fig. 7 Comparison of power-recovery factors for vented and unvented straight-walled amplifier

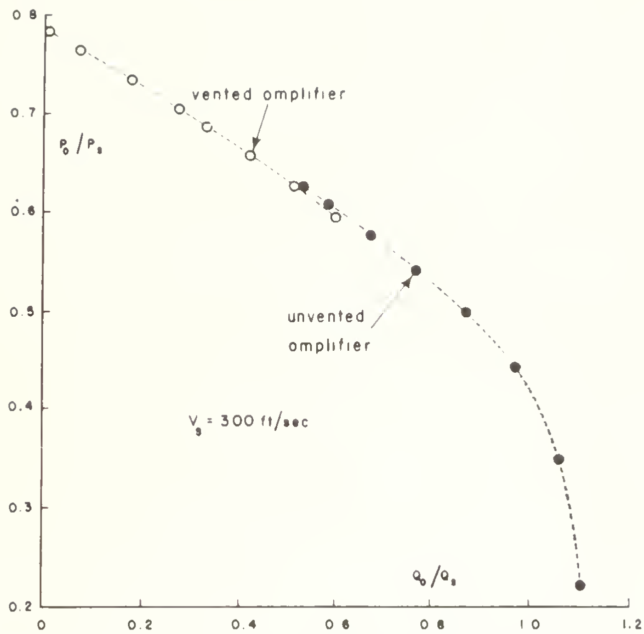

Fig. 8 Pressure-recovery versus normalized active-portflow for a concave-walled amplifier (closed control ports)

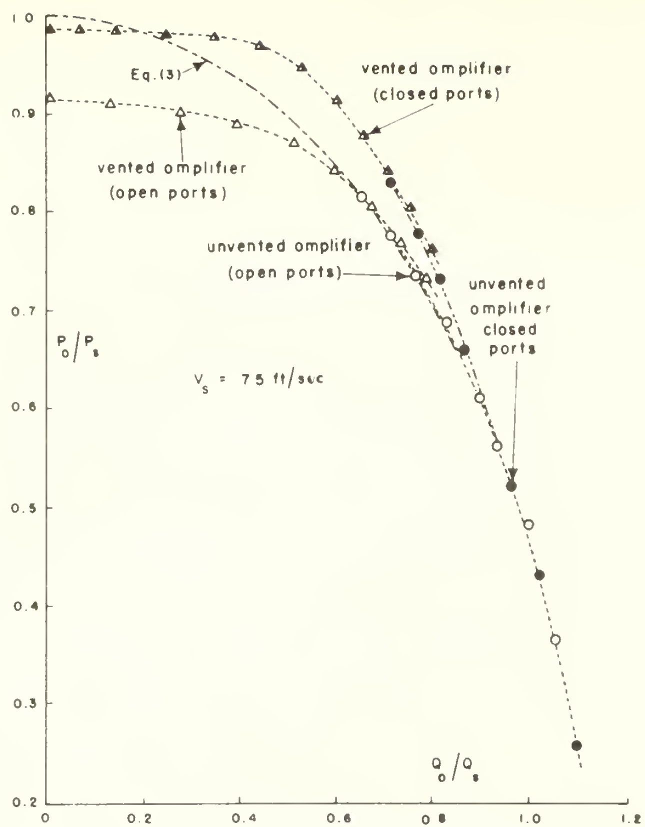

Fig. 9 Pressure-recovery versus normalized active-port flow for a convex-walled amplifier for open and closed control port operations (V = 75 ft/sec)

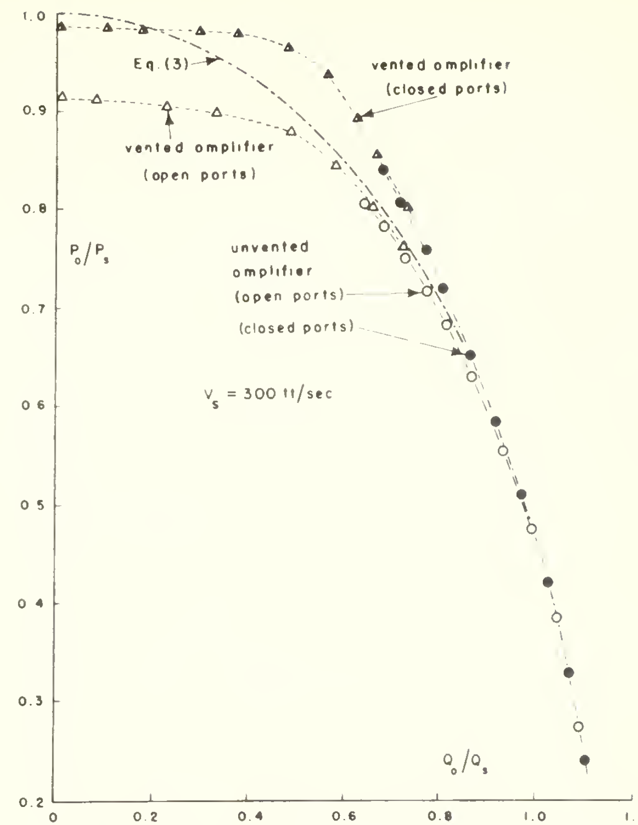

Fig. 10 Pressure-recovery versus normalized active-port flow for a convex-walled amplifier for open and closed control port operations (V = 300 ft/sec)

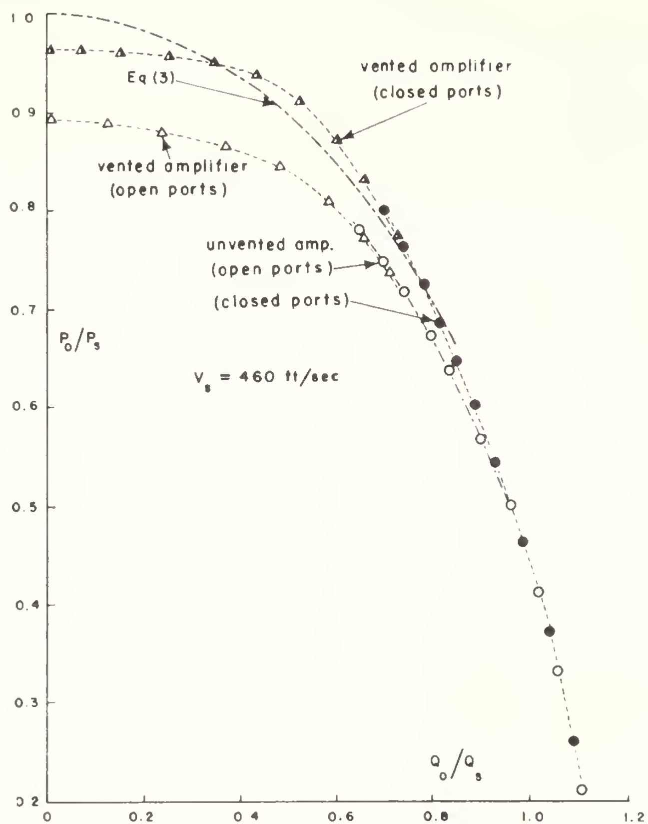

Fig. 11 Pressure-recovery versus normalized active-port flow for a convex-walled amplifier for open and closed control port operations (V_s = 460 ft/sec)

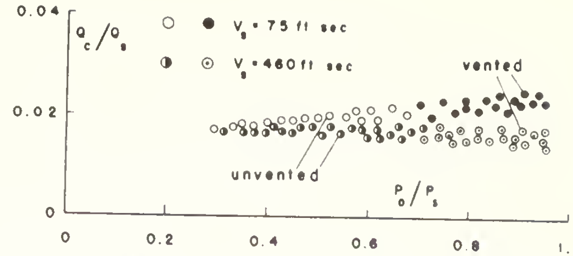

Fig. 12 Control flow characteristics of the convex-walled amplifier

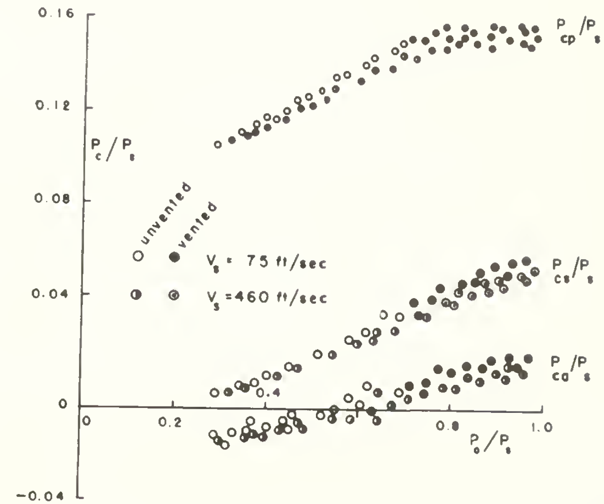

Fig. 13 Control pressure characteristics of the convex-walled amplifier

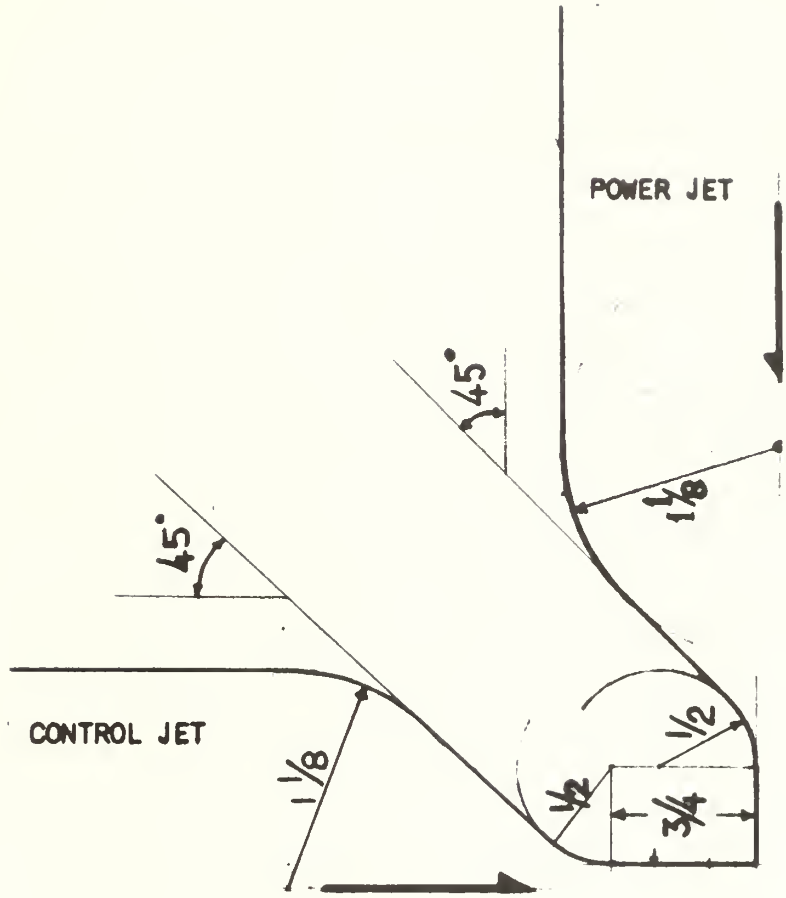

FIG. 14 STREAMLINED NOZZLE CONFIGURATION

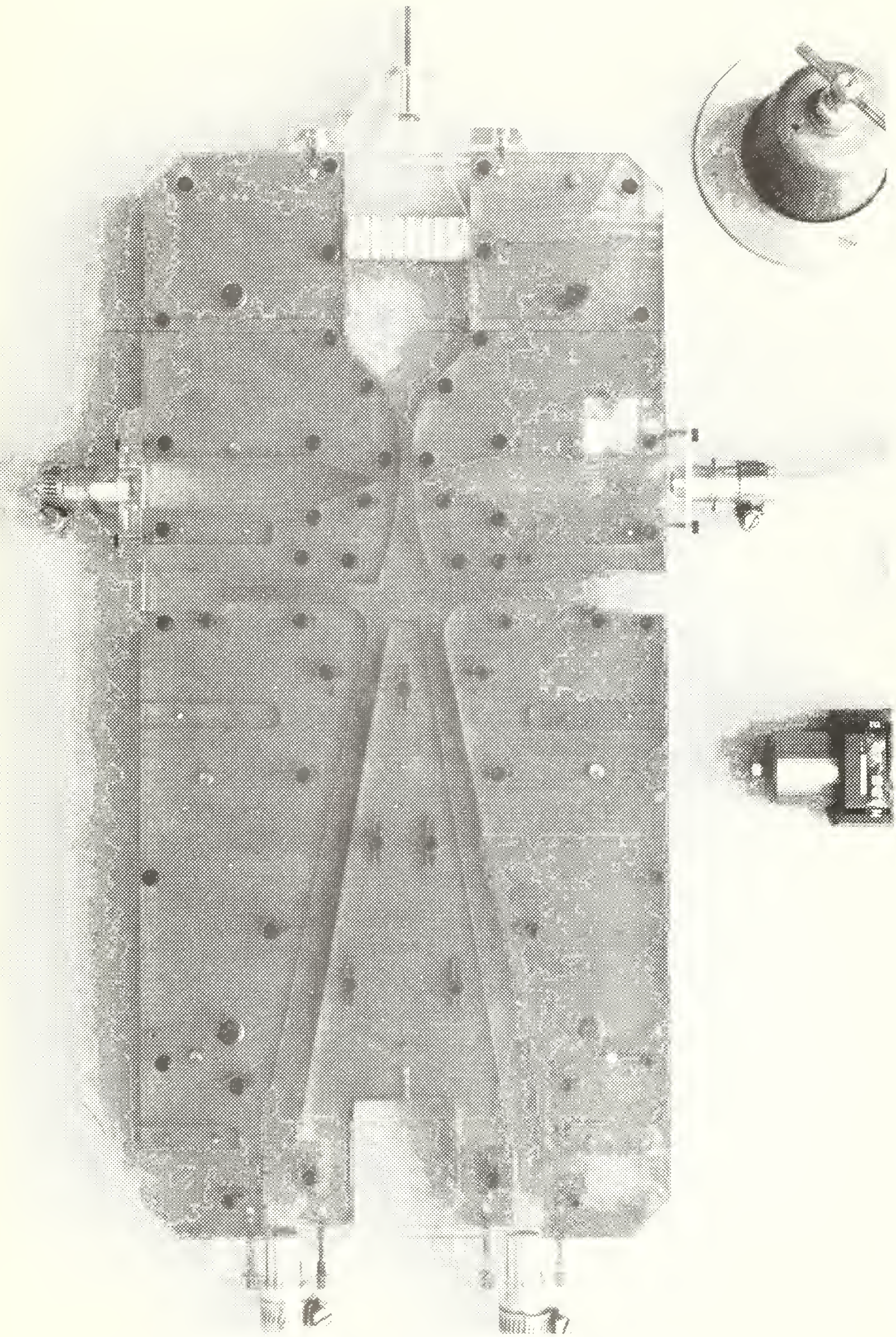

FIG. 15 MODIFIED CONVEX-WALLED BISTABLE AMPLIFIER

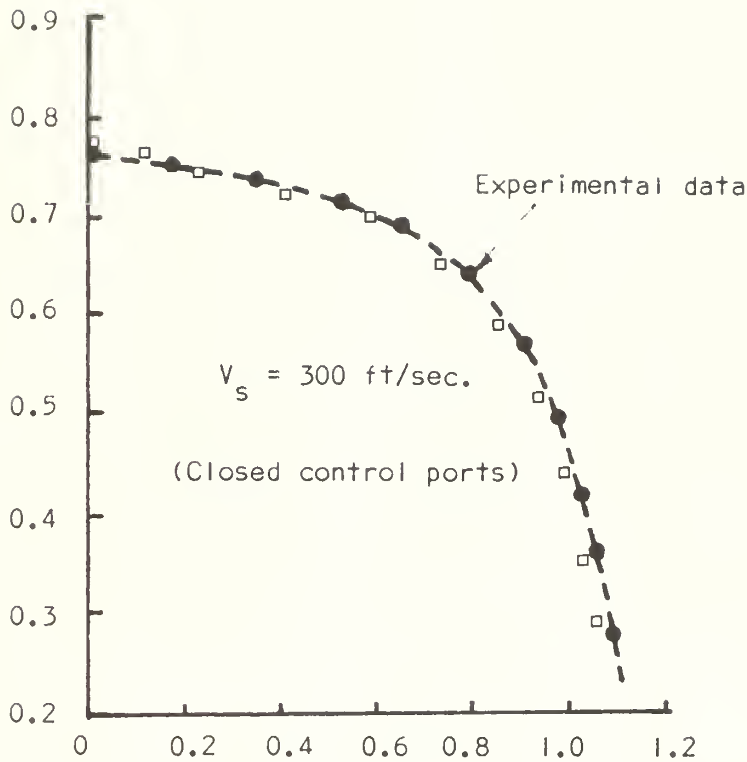

FIG. 16 Pressure-recovery versus normalized active-port flow for the modified convex-walled amplifier for closed control-port operations (V_s = 300 ft/sec).

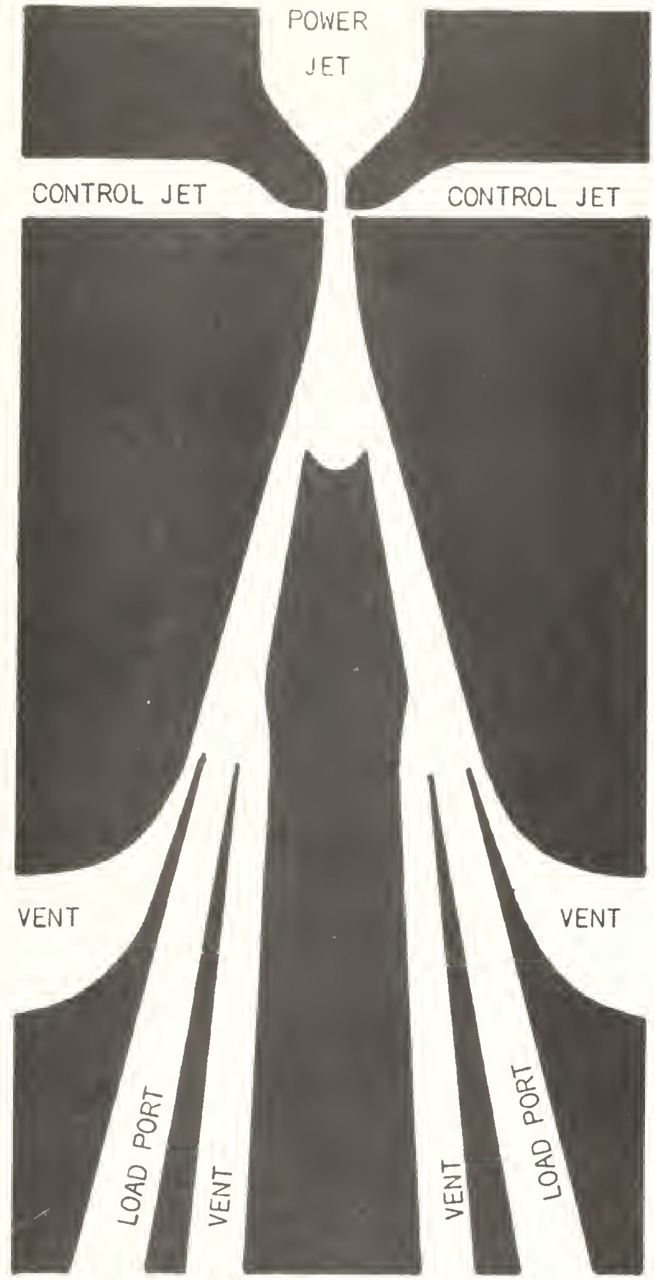

FIG. 17 THE NEW AMPLIFIER CONFIGURATION

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The results of a comprehensive study of the comparative performance characteristics of geometrically similar vented and unvented bistable amplifiers, together with their actual dimensions, are presented. The Reynolds number in the tests ranged from 9,750 to 60,000, Mach number from 0.07 to 0.42, and the power jet velocity from 75 to 460 ft/sec. Each amplifier as conceived and designed was capable of giving a maximum of geometric flexibility which enabled a systematic evaluation of the shape and location of the splitter plate and Coanda walls. It was found, within the range of Reynolds and Mach numbers tested, that certain gain characteristics and the range of operation of a given unvented amplifier overlap, within a narrow range of P_0/P_s and Q_0/Q_s values, with the corresponding gain characteristics and the range of operation of the vented amplifier. It was also found that a convex-walled amplifier with proper geometry exhibits considerably better performance characteristics than are normally associated with such devices. Finally, a new bistable amplifier with vents located in the load ports has been introduced.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fluidics Bistable amplifier Convex-walled bistable amplifier						

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